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Dynamic Double Directional Propagation Channel Analysis with Dual Circular Arrays[†]

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Abstract

A high-resolution dynamic double-directional channel sounding campaign has been conducted at 5 GHz using a pair of identical 16-element circular patch arrays. An important feature of this measurement configuration is its ability to provide an instantaneous full azimuth view of the channel from both ends, hence the relationship between direction of arrival (DoA) and departure (DoD) can be assessed. For the environments considered, the post-processed results indicate that the distributions of both DoA and DoD are dependent on each other, such that most multipath components (MPCs) concentrate around the direction where both terminals face each other. This effect is observed in both line of sight (LOS) and non LOS (NLOS) propagation conditions. Further, the global distributions of the MPCs are found to exhibit a Laplacian characteristic with its peak located at region where both terminals face each other.

I. Introduction

Wireless Local Area Networks (WLANs) provide wideband wireless connectivity between PCs and other consumer electronic devices as well as access to the core network and other equipment in corporate, public and home environments. Currently, WLAN technology operating in the 2.4 GHz ISM band is widely used, however it has been recognised that this band is no longer ideal for future WLAN systems due to high level of interference and lack of spectrum. Hence, there is considerable interest in the deployment of WLAN technology in the 5 GHz band through the IEEE 802.11 standard. In addition, there is significant interest in the use of Multiple-Input Multiple-Output (MIMO) technologies in order to obtain throughput enhancements. Thus, it is vital to understand 5 GHz MIMO propagation channels in detail in order to specify future WLAN operational modes and standards.

A prerequisite for the utilisation of MIMO based signal processing is a good understanding of the spatial domain properties of the channel as viewed from the transmitter (Tx) and receiver (Rx). Here, special attention is given to the spatial domain characterisation of the 5 GHz double-directional propagation channel as this provides valuable inputs to activities such as the European COST 273 MIMO channel modelling task. Extensive dynamic double-directional channel sounding campaigns have been conducted at the University of Bristol (U.K.) in order to obtain sufficient channel statistics to support this task. Several environments suitable for future WLAN deployment at 5 GHz have been chosen. An important feature of this measurement technique is its ability to evaluate the joint statistics between the DoA and DoD in full azimuth view of both ends of the wireless link. In addition, birth-death statistics of the MPCs in a particular environment can also be evaluated as dynamic measurement mode was employed, however a description of this is beyond the scope of this paper. The analysis presented here shows that distributions of DoA and DoD are dependent on each other under most propagation scenarios (LOS and NLOS). Further, it is observed that MPCs concentrate around the direction in which both Tx and Rx face each other, and also in regions in which one of them faces the opposite direction. Here, the main objective of this paper is to present these observations by means of some samples of post-processed results, gathered from recent measurement campaigns.

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The paper starts with a brief description of the patch antenna array design in Section 2, and is followed by an overview of the channel sounding campaign in Section 3. The data processing method and some samples of post-processed results are then discussed in Section 4. Finally, Section 5 concludes the paper.

II. Antenna array designs

As the main objective of this work was to analyse the relationship between DoA and DoD of a wireless propagation channel, the measurements must be able to support high-resolution multipath parameter extraction. Therefore, the antenna array design plays an important role in order to meet this goal. In [1], the authors had assessed the quality of post-processed results when using several algorithms and different candidate antenna arrays. Of those tested, it was concluded that the patch antenna provided the best results in the direction finding problem with a circular array. Hence, two identical 16-element uniform circular arrays were constructed using dual-polarised (horizontal and vertical) circular stacked patch antenna elements. The patch antenna was designed using an in-house Finite Difference Time Domain (FDTD) tool at Bristol and further details can be found in [2]. It was observed that the simulated response using FDTD tool matches very closely with the real measured response. Figure 1a shows the geometry of interest of the patch element, while Figure 1b shows the measured return loss plot of a sample patch element.

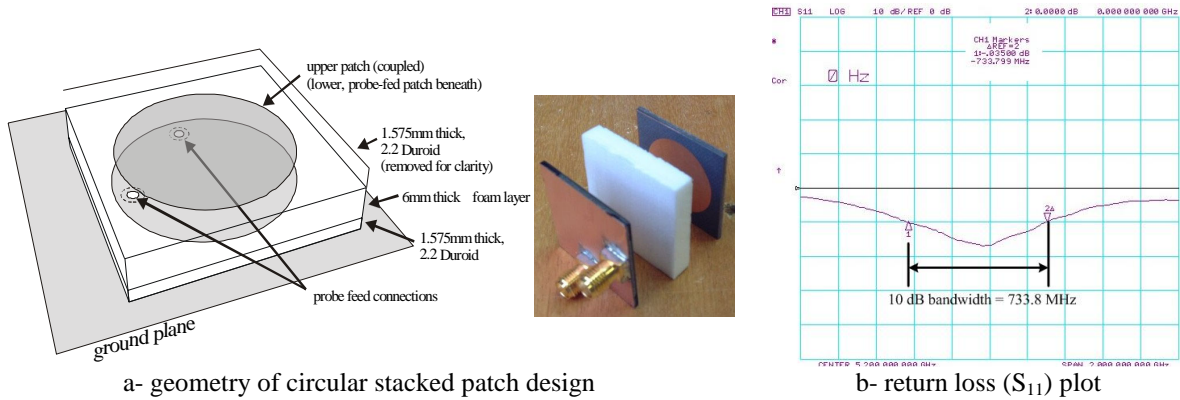


Figure 1: Design and response of circular stacked patch antenna

The 16-element uniform circular patch arrays (UCPAs) (Figure 2a) have a radius of 1.28λ . The patches were mounted in the middle of a vertical cylindrical ground plane with an overall length of 6λ . Spatial calibration process was conducted prior to the measurement in an anechoic chamber. Here the real response over a full azimuth range was recorded in 0.5° angular steps using the Medav RUSK BRI channel sounder with same parameter settings as used in real measurement campaigns. In addition, two separate array switching units (shown in Figure 2b mounted below a UCPA) were constructed as an external interface between the UCPA and the sounder core units. These additional units provide synchronised MIMO sequential switching sequence at both the transmitting and receiving arrays. It should be noted that, although the arrays were dual polarised, only vertical polarisation was considered during the measurement.

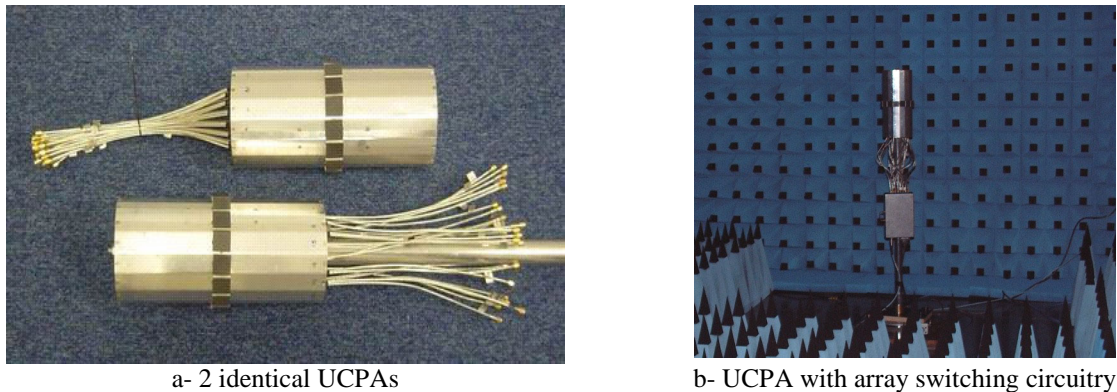


Figure 2: 16-element UCPA

III. Channel sounding campaigns

The measurements were conducted using a carrier frequency of 5.2 GHz and measurement bandwidth of 120 MHz using a Medav RUSK BRI channel sounder. The transmitting and receiving units of the sounder were accurately synchronised in both time and frequency through the use of an optical fibre connecting both units at all times. Back-to-back system calibration was performed every time prior to measurements in order to remove any intrinsic response of the sounder from the measurements and residual delays in the triggering events and cables connecting the antenna and sounder. The frequency domain channel responses were calculated online and stored on the sounder's hard disk for subsequent post-processing.

Dynamic measurements were conducted by slowly (approximately 0.2 m/s) pushing either the transmitting or receiving UCPA (dynamic end) on a customised measurement trolley along a predefined route, while the other end was fixed at certain location (fixed end). The height of the dynamic end was 1.7 m from ground at all times, while the height of the fixed end was either 1.7 m (to emulate peer to peer transmission) or approximately 2.1/2.5/3.0 m (to emulate access point transmission). During the whole measurement process, all efforts were made to ensure the minimum obstruction by the person pushing the trolley from the spatial region of interest.

Several environments suitable for the deployment of WLAN systems were chosen for the measurements. These included:

1. Two different large modern offices – Office 'A' and Office 'B'
2. Laboratory
3. Corridor and adjacent offices
4. Open foyer
5. Outdoor courtyard – hotspot environment
6. Indoor to outdoor (limited database)

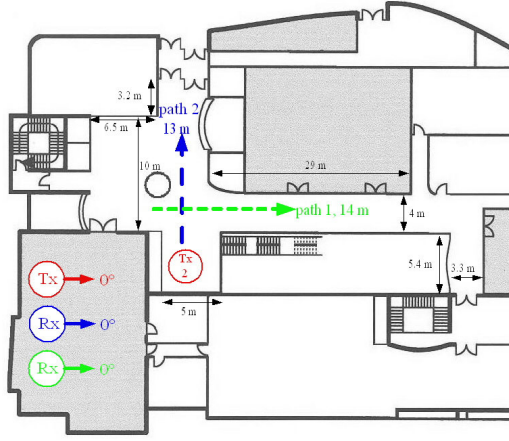
Measurements were conducted under different propagation conditions as follows.

1. LOS
2. Obstructed LOS (OLOS)
3. NLOS
4. Populated - during normal office hours, no restriction was imposed on the channel
5. Unpopulated - during off office hours and night time, less than 5 people
6. Different heights for the fixed terminal, e.g. 1.7/2.5/3.0 m from ground

The measurement environments and conditions were carefully chosen in order to reflect real channels and to represent most possible propagation conditions that will occur. Due to space limitation, only environments and measurement setup corresponding to analysis presented in the following section are described here. Further descriptions, pictures and additional floor plans of the measurement environments are available in [3].

Figure 3 shows the floor plan and picture of measurements conducted in an open foyer environment, which is a large open area with sparse furniture around the space. The floor is carpeted and the walls are made of bricks and concrete. It has a large 'glass roof' and a large gap between the 1st and 2nd level (measurements were conducted on 2nd level). The heights of both Tx and Rx were fixed at 1.7 m from ground (measured from the centre point of the patch elements), emulating peer to peer connection. The Tx was stationary at 'location 2' (Tx 2), while the mobile Rx was pushed with a customised measurement trolley along 2 different dynamic paths (labelled as 'path 1' and 'path 2'). As both Tx and Rx faced each other during the whole measurement run (at different DoD/DoA along the path), LOS condition was available in these particular measurements.

On the other hand, Figure 4 shows the floor plan and picture of measurements conducted at a research laboratory environment. It is highly cluttered with many scatterers all around the places. The concrete floor is not carpeted, and the walls are made of bricks and concrete. The mobile Rx was pushed along 'path 2', while 2 different locations were chosen for the stationary Tx. Similarly, for the following analysis, the heights of both Tx and Rx were fixed at 1.7 m from ground. As the LOS path of the terminals was obstructed by shelves and scatterers near the Tx at all times, the conditions were considered to be a combination of OLOS and NLOS for these particular measurements.

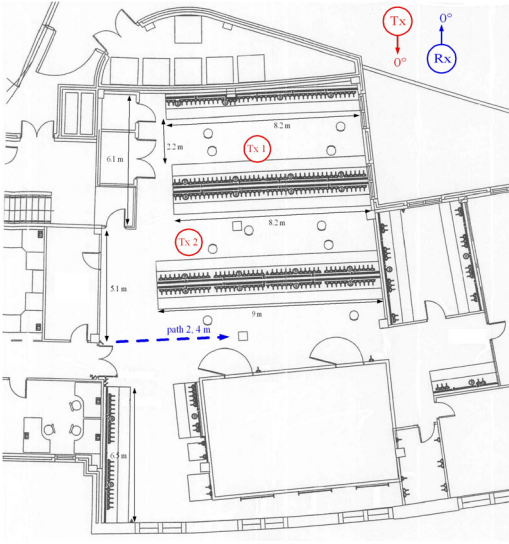


a- 'Tx 2' measurements (LOS)



b- mobile Rx along 'path 1' and stationary 'Tx 2'

Figure 3: Floor plan and picture of the foyer measurements



a- measurements for dynamic 'path 2' (OLOS/NLOS)

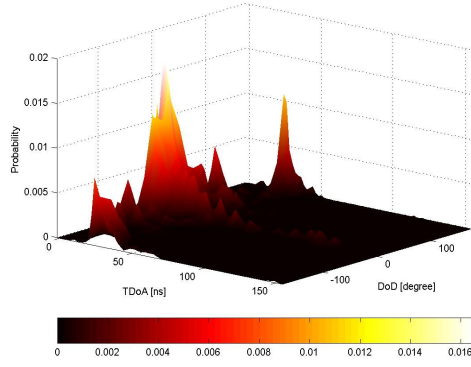


b- mobile Rx along 'path 2'

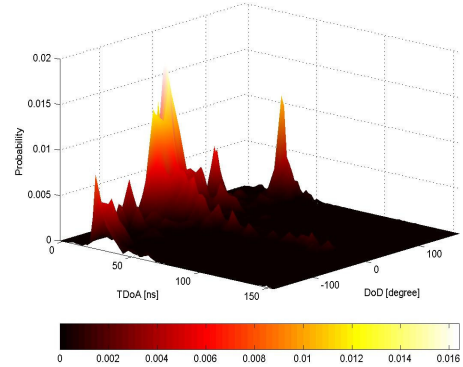
Figure 4: Floor plan and picture of the laboratory measurements

IV. Data processing and results

Due to the iterative nature of the classical Space-Alternating Generalised Expectation-maximisation (C-SAGE) algorithm, processing a large multi-dimensional database will require an enormous amount of time and computing resources. In order to achieve significant timesaving and complexity reduction, the hybrid-space SAGE (HS-SAGE) [4] algorithm was employed to jointly extract DoA, DoD, and time delay of arrival (TDoA) of the MPCs. Briefly, HS-SAGE algorithm comprises a combination of element-space and beamspace processing. In this particular campaign, TDoA parameter had been extracted in beamspace domain within the HS-SAGE algorithm. It has been proven that HS-SAGE algorithm achieves a same performance as the C-SAGE algorithm (in terms of convergence characteristics and estimation accuracy), but with reduced overall processing time. Figure 5 shows a direct comparison of the 2-D joint PDF between the extracted TDoA (normalised to first arrival path) and DoD of the MPCs in an office LOS environment [3]. It can be seen that the distributions are the same as each other despite the fact that TDoA was extracted in beamspace domain for the HS-SAGE algorithm. However, an enormous amount of time and computing resources were saved during the vast processing task of the whole office LOS database. This brings significant benefits especially in stochastic channel modelling activities as the statistics of the channel can be obtained using significantly less offline processing resources.



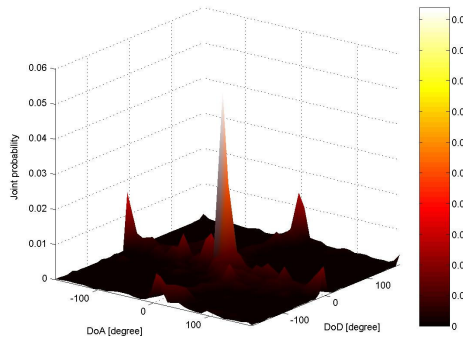
a- estimated results using HS-SAGE



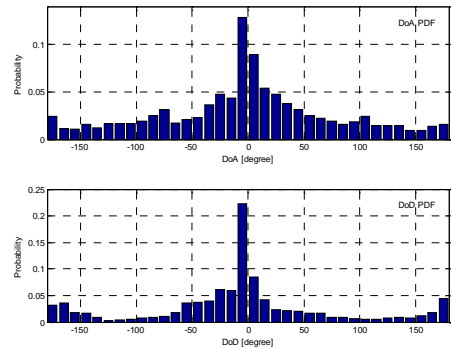
b- estimated results using C-SAGE

Figure 5: 2-D joint PDF between TDoA and DoD for Office 'A' LOS measurements [3]

In order to have a better insight into the overall dependency between DoA and DoD, the array orientations were normalised such that both Tx and Rx faced each other at their respective 0° throughout the whole dynamic path. Here, samples of post-processed results for Foyer 'Tx 2' LOS measurements (Figure 3) and Laboratory 'path 2' OLOS/NLOS measurements (Figure 4) are shown in Figures 6-8. Figures 6a and 7a present the 2-D joint distributions between DoA and DoD parameters. It can be observed that MPCs concentrated around the direction in which both Tx and Rx faced each other (indicated by peak at centre), and also in regions in which either one of them faced the opposite direction (indicated by peaks at the sides of figure, mostly due to back wall 1st order reflections). As the spatial dispersion in LOS condition was smaller, it has narrow peaks. From the global distribution of DoA and DoD parameters in Figure 6b, a Laplacian distribution can be observed in LOS case. The DoA and DoD global distributions for NLOS cases (Figure 7b) were considered uniform across the azimuth (due to local scattering), except at region where both Tx and Rx faced each other whereby a weak Laplacian characteristic was observed. This shows that both DoA and DoD were not evenly and independently distributed across the azimuth as their distributions relied on both the orientation of Tx and Rx (in case of full azimuth coverage).



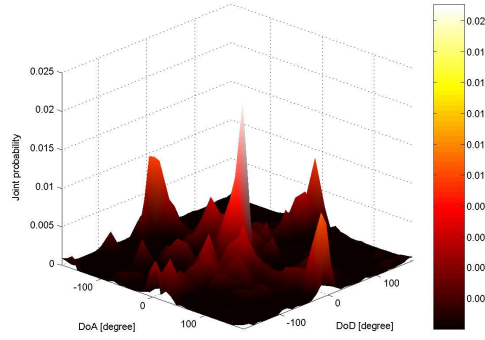
a- 2-D joint distribution of DoA and DoD



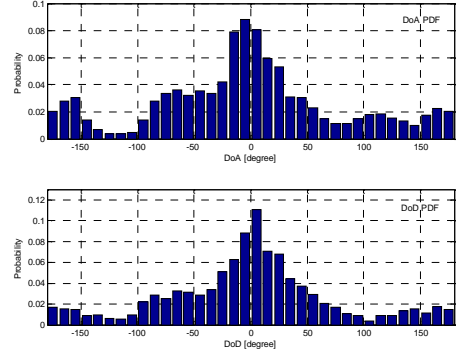
b- global distributions of the DoA/DoD

Figure 6: Statistical results for Foyer 'location 2' measurements (LOS)

When path gain (power) was taken into consideration, the channel was found to be dominated by MPCs propagating along the direction where both ends faced each other. This effect was shown in 2-D power density distributions across the DoA and DoD spaces (Figure 8) in which the effect of path gain was taken into consideration. Again, it can be seen that the power azimuth profiles exhibit Laplacian characteristics. Also, it can be observed that 1st order reflections contributed considerable amount of power in the channel (indicated by the smaller peaks at the sides of figure). Other MPCs at other directions had less power contribution to the channel. However, they still played an important role in randomising the MIMO subchannels, i.e. enhancing the capacity in a MIMO channel. Although not presented here due to space limitation, similar results were also obtained for other measurements in other environments.

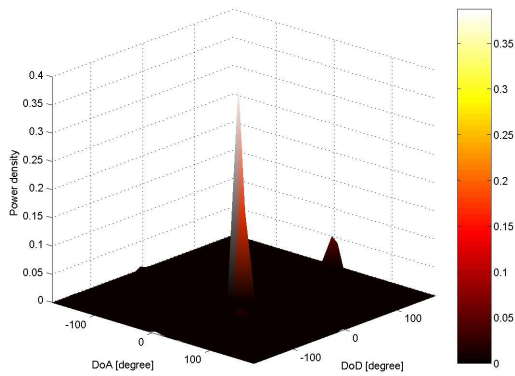


a- 2-D joint distribution of DoA and DoD

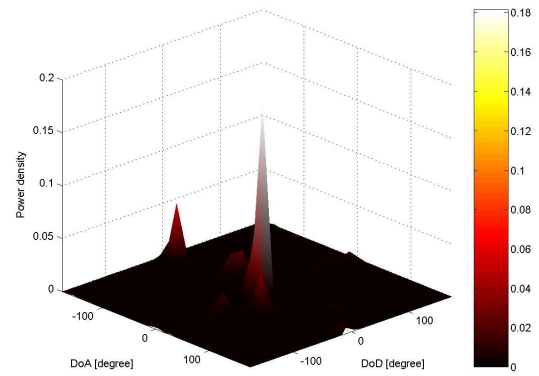


b- global distributions of the DoA/DoD

Figure 7: Statistical results for Laboratory 'path 2' measurements (OLOS/NLOS)



a- for Foyer 'location 2' (LOS)



b- for Laboratory 'path 2' (OLOS/NLOS)

Figure 8: 2-D power density between DoA and DoD

V. Conclusions

This paper has presented the joint distributions between the DoA and DoD parameters in a MIMO propagation channel. It was observed that their distributions were highly dependent on each other as they were not evenly and independently distributed across the azimuth, including that of OLOS and NLOS cases. It was found that MPCs concentrated around the region where both Tx and Rx faced each other, and at region where one of them faced the opposite direction (mostly due to back wall reflections). When power distribution was taken into account, it was found that the channel was dominated by MPCs propagating along the direction where both ends faced each other, including that of OLOS and NLOS cases. Further, it was observed that the power azimuth profiles exhibited a Laplacian characteristic.

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